

# **STARLOG**

## **Thermocouples and RTD's (Resistive Temperature Devices)**

**Model 7400K**

**Model 7400F**

**PT100**

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## 1. INTRODUCTION

This supplement provides information about thermocouples and Resistive Temperature Devices (RTD's). It includes information on connecting these devices to a Data Logger and using them in a Data Logging Scheme. The examples given describe the usage of a type K thermocouple **and** the usage of a PT 100, an RTD.

Other RTD's include the Model 6507 Thermistor Temperature Probes. These probes are described in another supplement, (see Temperature Probes, supplement 6207).

The following STARLOG products are described in this supplement:

Model	Description
Model 7400K	Type K - Welded Tip Thermocouple
Model 7400F	Thermocouple Mounting Tape

The Type K Welded Tip Thermocouple is a base metal system using nickel alloys. These probes are ideal for measuring high temperatures. Typical applications are:

- vehicle/locomotive exhaust
- engine temperatures
- oil heaters
- water pipes

The Model 7400F Thermocouple Mounting Tape is backed by a silicone thermosetting adhesive which will not carbonize at elevated temperatures. The tape is specifically designed for high temperature exposure and therefore ideally suited to mount thermocouples. It also provides electrical isolation of the hot junction.

## **2. THERMOCOUPLES**

Thermocouples provide an economic means of measuring temperature with many advantages:

- They can be extremely robust (when made of thick wire).
- They can respond quickly (when made of thin wire).
- They measure over a wide range (from -270 to 3000°C).
- They are manufactured in a wide range of probes and packages.
- The common types comply with international standards and are therefore interchangeable.

### **2.1 Thermocouple Principle**

A thermocouple consists of two pieces of dissimilar “metal” (usually in the form of a wire) which are joined together at one end (fused or welded). This is known as the **HOT END** or Measurement point. The other end is connected to a voltage measuring instrument (perhaps via an intermediate “cold junction”). This is known as the **COLD END** or the Reference point. A temperature difference between the **HOT** and **COLD END** causes a voltage to be produced which is approximately proportional to the **HOT/COLD** temperature differential.

### **2.2 Cold Junction Reference**

Because the thermocouple is basically a differential device, the absolute temperature being measured can only be determined if the reference temperature is known. (Also, the accuracy of the measured absolute temperature can never exceed the accuracy of the reference temperature).

The reference temperature is known as the Cold Junction temperature and the calculation (adding the Cold Junction temperature equivalent to the thermocouple output is known as Cold Junction Compensation).

Normally, the Cold Junction (and its temperature) is where the thermocouple wire terminates to the measuring device. The temperature of this termination must be measured by another type of temperature sensor (e.g. thermistor) and

this temperature (or its microvolt equivalent) is added to the nett thermocouple output to produce the true HOT END temperature.

## 2.3 Cold Junction Options

There are three cold junction compensation facilities available when measuring thermocouples with a MACRO Data Logger.

1. **Internal Reference** . . . the MACRO Data Logger measures its own temperature using one of its internal channels. This temperature is available for recording and can also be used as a representative temperature in a cold junction compensation.

This method will allow cold junction temperatures to be measured within a 1 to 3°C accuracy, provided the MACRO Logger and the thermocouple termination strip are inside a weatherproof enclosure both within a stable ambient temperature environment.

Overall absolute measurement accuracies better than 5°C should be achievable. (see “Linearisation” below)

2. **External Reference** . . . another method uses a “red thermistor” bonded to the thermocouple termination strip in an “isothermal manner” and connected to one of the 16 input channels. The cold junction temperature can then be measured to 0.2°C accuracy, thereby allowing an overall absolute accuracy of 0.5 to 0.75°C to be maintained. (See “Linearisation” below.)

3. **Relative Measurement** . . . allows just the pure thermocouple EMF to be measured. The cold junction temperature and associated compensation (if needed) is the user’s concern.

Resolutions of 0.05°C can be achieved. (See “Linearisation” below.)

## 2.4 Thermocouple Accuracy

Good quality thermocouples can be used to measure absolute temperatures to 0.5°C accuracy. With laboratory calibration, this can be improved to 0.2°C.

Thermocouples are normally matched by manufacturers to better than 0.75% of calibrated range.

When extension or compensating cable is used with a thermocouple, their accuracy is further reduced.

When measuring relative temperatures, much greater resolution can be achieved (down to  $0.05^{\circ}\text{C}$ ) between the HOT and COLD ENDS and this can be used to good effect when measuring differential temperatures. (Remember, don't expect high absolute accuracy).

## 2.5 "Low Cost" Thermocouples

It is possible to make "low cost" thermocouples from sections of the appropriate thermocouple extension cable (not compensating cable). If this is done, the accuracy cannot be guaranteed, though calibration will help. High and low temperature performance will also be unpredictable.

## 2.6 Types of Thermocouple

There are many hundreds of type of thermocouple (some 3000 types may be purchased). Most of these are manufactured from "metals", but some are made of semiconductors and graphite/ceramic materials.

In normal use, seven major types are used. These thermocouples are normally manufactured to meet international standards (e.g. BS4937, ANSI/MC96.1, DIN437 10, JISC 1602). Their uses and characteristics are listed below:-

Type	Material	Range	Output	Notes
K	Nickel/Chromium (+ve) Nickel Aluminium (-ve)	-200 to 1100°C	39 to 43 $\mu\text{V}/^{\circ}\text{C}$	Most common type, general purpose
J	Iron (+ve) Copper/Nickel (-ve)	-20 to 700°C	46 to 59 $\mu\text{V}/^{\circ}\text{C}$	Iron rusts at low and oxidises at high temperatures
T	Copper (+ve) Copper/Nickel (-ve)	-250 to 350°C	45 to 46 $\mu\text{V}/^{\circ}\text{C}$	Low temperature, cryogenic uses
E	Nickel/Chromium (+ve) Copper/Nickel (-ve)	0 to 800°C	65 to 81 $\mu\text{V}/^{\circ}\text{C}$	High EMF, suitable for vacuum

Table continued on next page . . .

Type	Material	Range	Output	Notes
R	Platinum/1 3% Rhodium (+ve) -Platinum (-ve)	0 to 1500°C	8 to 13µV/°C	Stable, high temperature, low oxidation, easily contaminated
S	Platinum/1 0% Rhodium (+ve) -Platinum (-ve)	0 to 1550°C	8 to 11µV/°C	Similar to R Type
B	Platinum/30% Rhodium (+ve) -Platinum/6% Rhodium (-ve)	50 to 1650°C	1 to 9µV/°C	See R Type. Can use Copper- Copper compensating cable

### 2.6.1 Extension/Compensation Cable

In some cases thermocouples need to be wired from a long distance (perhaps 100 metres or more). Quality thermocouple wire is very expensive, therefore thermocouple extension wire and/or compensation cable is used to cover the long distances close to the field (measurement point) to the termination (cold junction).

- Extension cable . . . is made of the same material as the thermocouple, but is of lower quality (and cost).
- Compensating cable . . . is made of different material (e.g. copper - copper/nickel) with the same thermal EMF characteristics.

Both extension and compensating cables can only be used within a limited temperature environment close to ambient. (e.g. 0 to 50°C). Outside this range, they do not match the thermocouple accurately and will introduce measurement errors.

## 2.7 Linearisation

Thermocouple EMF versus temperature is not linear. Some types of thermocouples are more linear than others (type K for instance). Two types of linearisation are available:

1. **In simple applications** . . . a linear approximation (over a restricted temperature range) can be used. This greatly simplifies the calculation of temperature and cold junction compensation.

The list below indicates the most usable ranges for the common thermocouple types along with their approximations and accuracy.

Type	Range (°C)	EMF(μV)	Error
K	-20 to 350	40.75	±1 °C
K	-50 to 1040	41.3	±5 °C
J	-30 to 180	44.6	±5 °C

Note: The common **It type** thermocouple does provide a workable range of temperatures using a simple linear approximation scaling. The J, T, E, R, S and B types have more limited usable ranges.

2. **For higher accuracy** . . . the thermocouple EMF measurement must be “linearised” by a mathematical calculation. Once determined, you can add the formula to the PDLOUT.FOR file to make it available for STARLOG Software. (See the Users Manual for details.) The inverse of this calculation must also be applied to the cold junction temperature measurement (to find the non-linearised equivalent thermocouple EMF at the cold junction temperature), before the cold junction compensation (EMF addition) can take place.

These correction polynomials are derived from the thermocouple standard reference tables and require a considerable amount of “computer processing” to calculate. Where possible, this form of linearisation should be processed using a fast computer with a maths co-processor.

### **3. RESISTIVE TEMPERATURE DEVICES**

Resistive Temperature Devices (RTD's) produce a change in resistance to correspond to a variation in temperature. An example of an RTD is the Pt 100 which is a platinum film resistance temperature detector. The temperature coefficient of the platinum film sensor is  $0.385/^{\circ}\text{C}$  so the lead resistance can be significant. To measure a change in resistance using a Data Logger it is necessary to convert its resistance change into a voltage variation which can be done using various techniques.

This supplement describes the most popular of these and also provides information on how other techniques may be employed. This supplement describes how to create a scheme to measure temperature over the specified range of the probe,  $-20^{\circ}\text{C}$  to  $60^{\circ}\text{C}$ , and also provides tables and information needed to measure other ranges.

Other RTD's, the Model 6507 Thermistor Probes are described in supplement 6207, *Temperature Probes*.

## 4. LOGGER CONFIGURATION

### 4.1 Using the K type Thermocouple

To use the Type K Thermocouple you will want to create a Scheme using the menu-driven STARLOG Software Package. This procedure is described below. The procedure differs depending on whether you use a Portable or MACRO Data Logger.

#### 4.1.1 Whether to Use a Portable or MACRO Data Logger

The Type K Thermocouple can be used with a MACRO Data Logger and providing a Model 61 10A Low Level Thermocouple Amplifier is used, a STARLOGGER or a Portable Data Logger. Details of how to install and use the Amplifier are found in the Field Termination & Signal Conditioning Modules supplement 6208.

#### 4.1.2 Configuring the Analog Channel Input Range

As the EMF generated by a thermocouple is small the input range for the MACRO must be changed from 0 to 5000mV to -50 to 50mV. This is achieved by creating a MACRO configuration table with the analog drive table shown below.

<b>Analog Drive Table</b>						
	<b>Input (mV)</b>					
<b>Channel 0</b>	<b>0 to 5000</b>	<b>Single Ended</b>	<b>X</b>	<b>X</b>	<b>8</b>	<b>2.55</b>
<b>Channel 1</b>	<b>-50 to 50</b>	<b>Single Ended</b>	<b>x</b>	<b>x</b>	<b>8</b>	<b>2.55</b>
<b>Channel 2</b>	<b>0 to 5000</b>	<b>Single Ended</b>	<b>x</b>	<b>x</b>	<b>8</b>	<b>2.55</b>
<b>Channel 3</b>	<b>0 to 5000</b>	<b>Single Ended</b>	<b>X</b>	<b>X</b>	<b>8</b>	<b>2.55</b>

### 4.1.3 Adding a Thermocouple and Cold Junction Reference to the Instrument List

There are three different methods of referencing the thermocouple to the cold junction (described in section 2.3). If the output of the thermocouple is referenced to a cold junction (Cases 1 and 2 in section 2.3) then the cold junction MUST be logged first in any scheme. This is necessary so that the formula in the transducer definition for the thermocouple uses the correct value for the cold junction.

If Model 7400 does not appear in the instrument list then an instrument must be created. The transducer definitions depend on whether the thermocouple is referenced to a cold junction. If the thermocouple is referenced to a cold junction then the transducer definition is:

<b>Edit a Transducer</b>	
<b>Transducer Description</b>	<b>Type K Thermocouple</b>
<b>Input Channel</b>	<b>h1 analog 1 (16 Bit)</b>
<b>Input Channel</b>	<b>-50 to 50</b>
<b>Transducer Range (mV)</b>	<b>-2.076 to 43.004</b>
<b>Transducer Scaling/Formula</b>	<b>Ktherm</b>
<b>Title for ReportsTemp</b>	
<b>Units of Result</b>	<b>deg C</b>
<b>Using String</b>	<b>####.#</b>

The formula Ktherm is given in Appendix A.

If the transducer is not referenced to a cold junction then the transducer definition is:

<b>Edit a Transducer</b>	
<b>Transducer Description</b>	<b>Type K Thermocouple</b>
<b>Input Channel</b>	<b>h1 analog 1 (16 Bit)</b>
<b>Input Channel</b>	<b>-50 to 50</b>
<b>Transducer Range (mV)</b>	<b>-2.076 to 43.004</b>
<b>Transducer Scaling/Formula</b>	<b>-50 to 1040</b>
<b>Title for ReportsTemp</b>	
<b>Units of Result</b>	<b>deg C</b>
<b>Using String</b>	<b>####.#</b>

The cold junction definitions are as follows, the first being for a cold junction being measured by the MACRO's internal temperature and the second being measured by a red thermistor.

## Cold Junction Using An Internal Channel

Edit a Transducer	
Transducer Description	Cold Junction
Input Channel	Temp Temperature
Input Channel	-5000 to 5000
Transducer Range (mV)	-5000 to 5000
Transducer Scaling/Formula	temp
Title for Reports	C.J.
Units of Result	
Using String	###.#

## Cold Junction Using A Red Thermistor

Edit a Transducer	
Transducer Description	Cold Junction
Input Channel	h0 analog 0 (16 Bit)
Input Channel	0 to 5000
Transducer Range (mV)	0 to 5000
Transducer Scaling/Formula	hired15
Title for Reports	C.J.
Units of Result	
Using String	###.##

### 4.1.4 Output Details

It is recommended that if you want to see a graph, generate a Lotus file. Note that STARLOG Software version 2.0xx does not support a graphical display of data in a Thermocouple Scheme.

Tabular output is supported.

## 4.2 Using the PT100

To use the PT100 with the MACRO Data Logger, you will want to set up a configuration table to configure the input range of the analog channel. This may be done using the menu-driven STARLOG Software Package.

Neither the STARLOGGER nor the Portable Data Logger are suitable as the analog input range is insufficient and they do not receive differential signals.

## 4.3 Configuring the Analog Channel Input Range

The PT100 sensor produces a differential output of 1.49 to 33.22mV DC for a temperature range of -20 to 60°C using the bridge completion technique described in section 5.2. The input channel should be set as differential with a range of 0 to 50mV (channel 0).

Analog Drive Table				
	Input (mV)		...	▪
Channel 0	0 to 50	Differential	X X 8	2.55
Channel 1	0 to 5000	Single Ended	X X 8	2.55
Channel 2	0 to 5000	Single Ended	XX8	2.55
Channel 3	0 to 5000	Single Ended	XX8	2.55
...				

## 4.4 Adding the PT100 to the Instrument List

From the Maintain Instruments menu select the command **Add a transducer** and enter the following attributes:

Edit a Transducer	
Transducer Description	PT100 Temp Sensor
Input Channel	h0 analog 0 (16 Bit)
Input Channel	0 to 50
Transducer Range mV	1.49 to 33.22
Transducer Scaling/Formula	-20 to 60
Title for ReportsTemp	
Units of Result	deg C
Using String	###.#

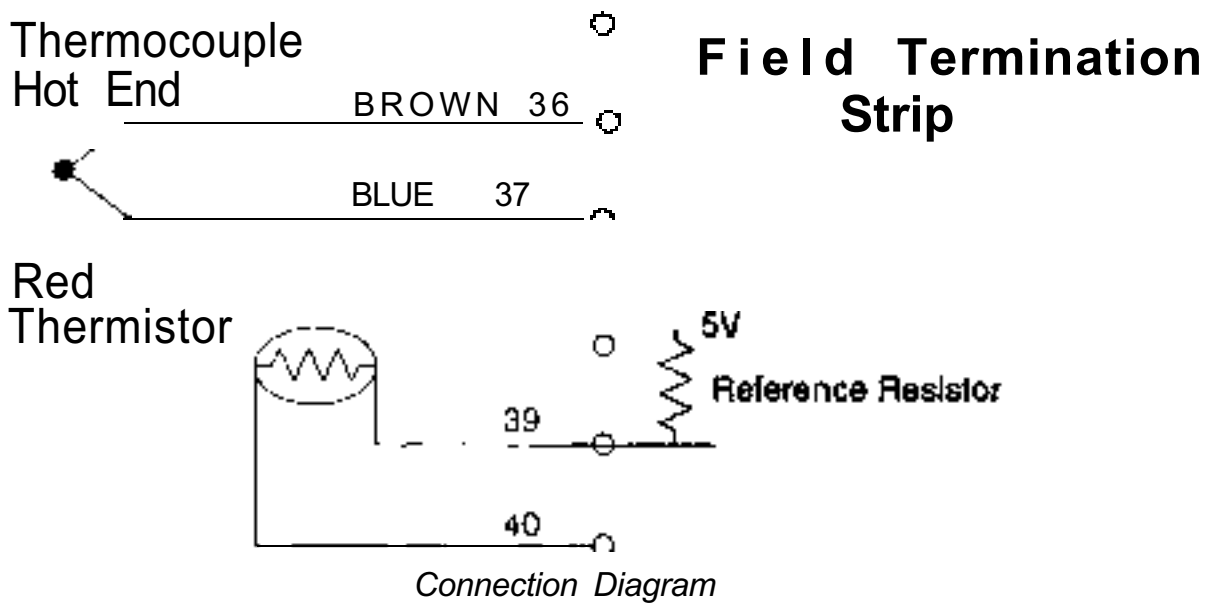
When the **Save Instrument** command is selected, this new instrument will be saved in the instrument list and can easily be selected when creating the scheme.

## 5. INSTALLATION

### 5.1 Thermocouple Installation

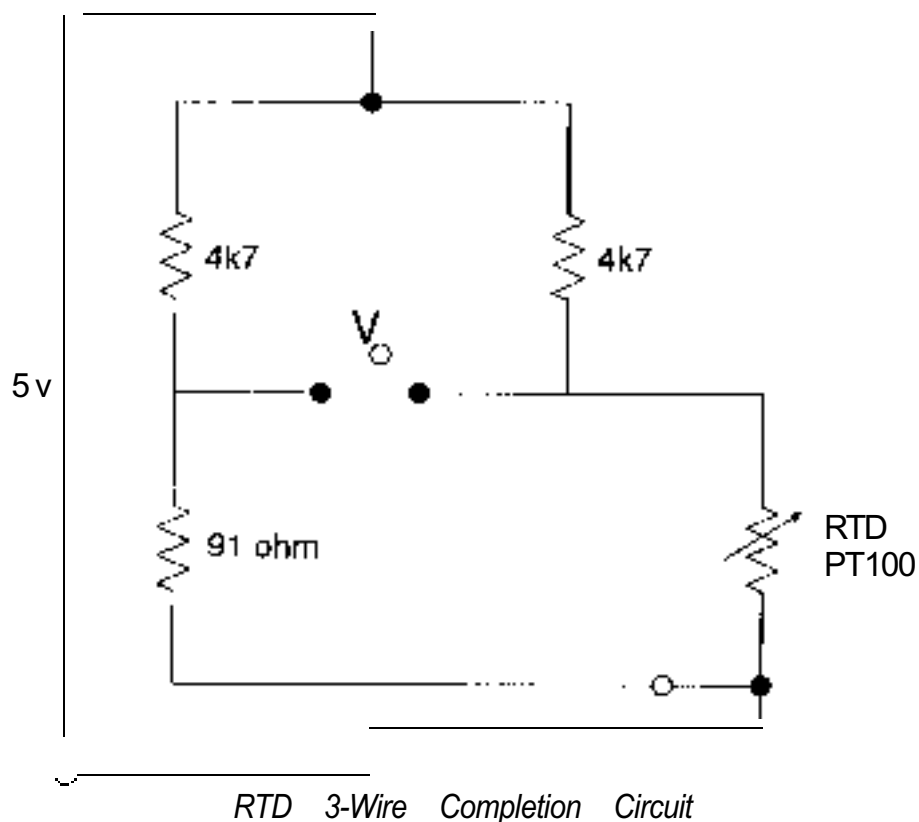
Up to 16 thermocouples may be connected to a MACRO Data Logger. If external cold junction referencing is used, one channel is used, leaving 15 channels to connect thermocouples.

A connection diagram is shown below which shows how one thermocouple can be connected to a MACRO Field Termination strip along with a thermistor to measure the temperature of the cold junction.

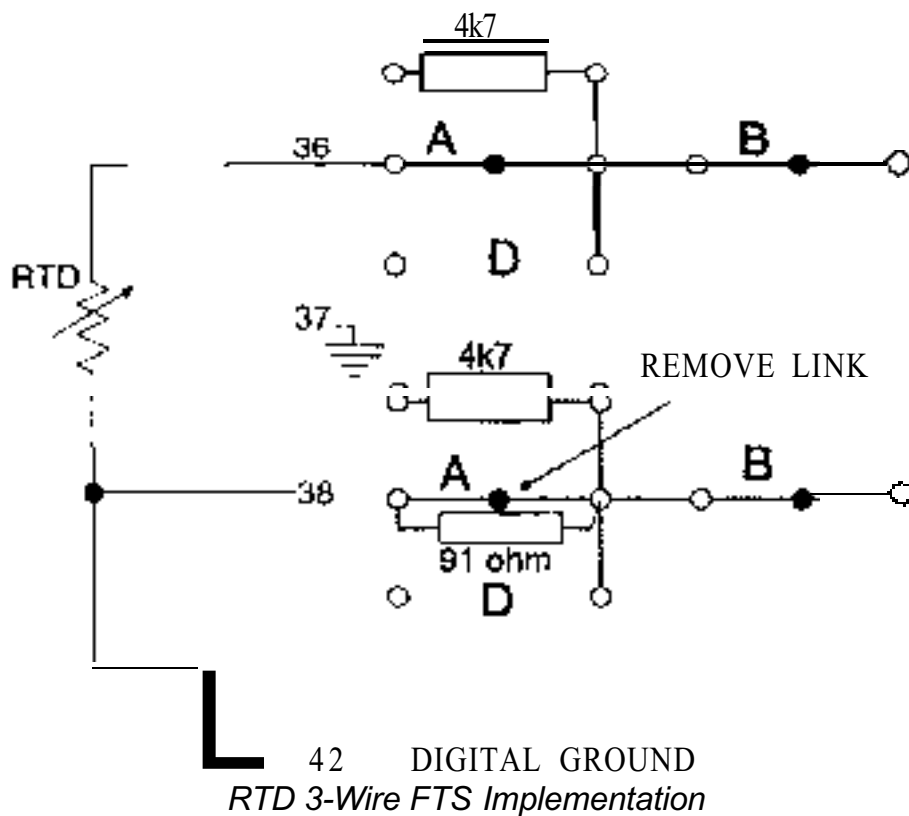


## 5.2 PT100 Installation

The probe must be connected to the analog channels as defined in the configuration table (section 2.4). The PT100 temperature sensor needs to be part of a bridge completion circuit. The circuit below shows a 3-wire completion circuit consisting of the PT100 and 3 bridge resistors.



This circuit can be realised on the MACRO FTS as indicated on the next page.



### 5.2.1 PT100 Connections

A connection table below shows how the probe can be connected to a MACRO Data Logger via a MACRO Field Termination Strip (Model 7100). It may also be connected to a signal connector (model 7101A), providing the bridge completion circuit is included for the temperature sensor.

If the instrument definition is as previously described and the bridge completion circuit has been fitted then the connections are as follows:

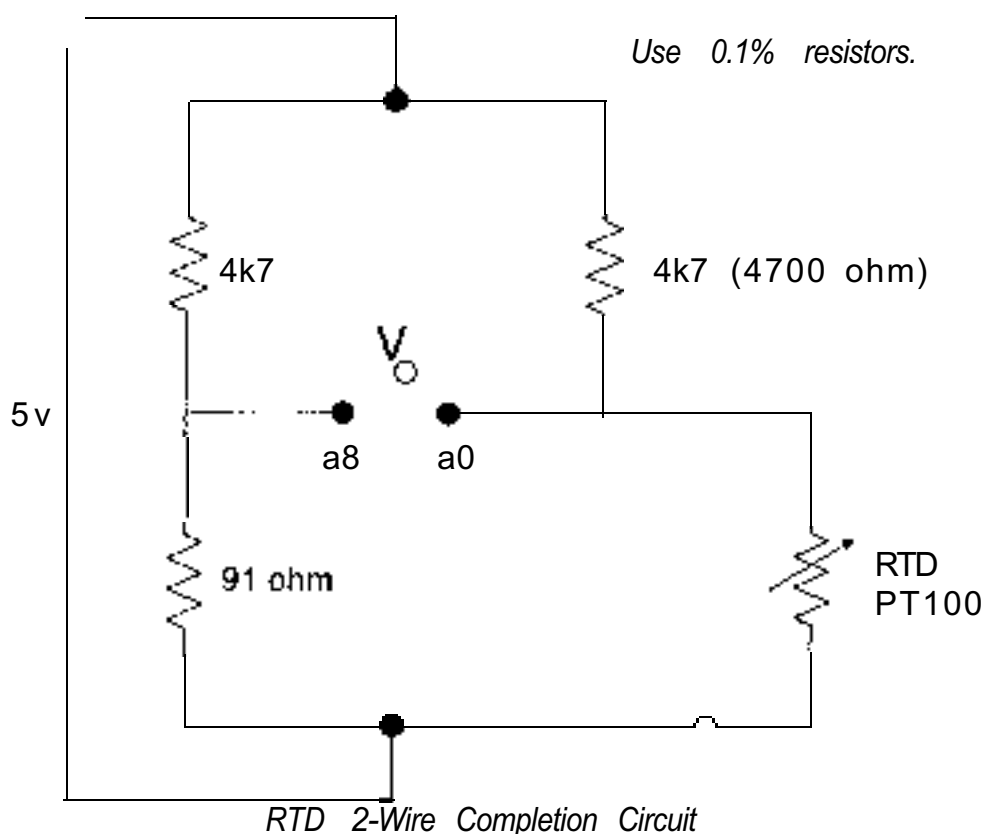
Channel	Wire Colour (e.g.)	Function	MACRO Pin	MACRO FTS Terminal
A0+	Yellow/white	Temperature	20	39
A0-	Green	Temperature	24	41
D Ground	Black	Ground	28	42

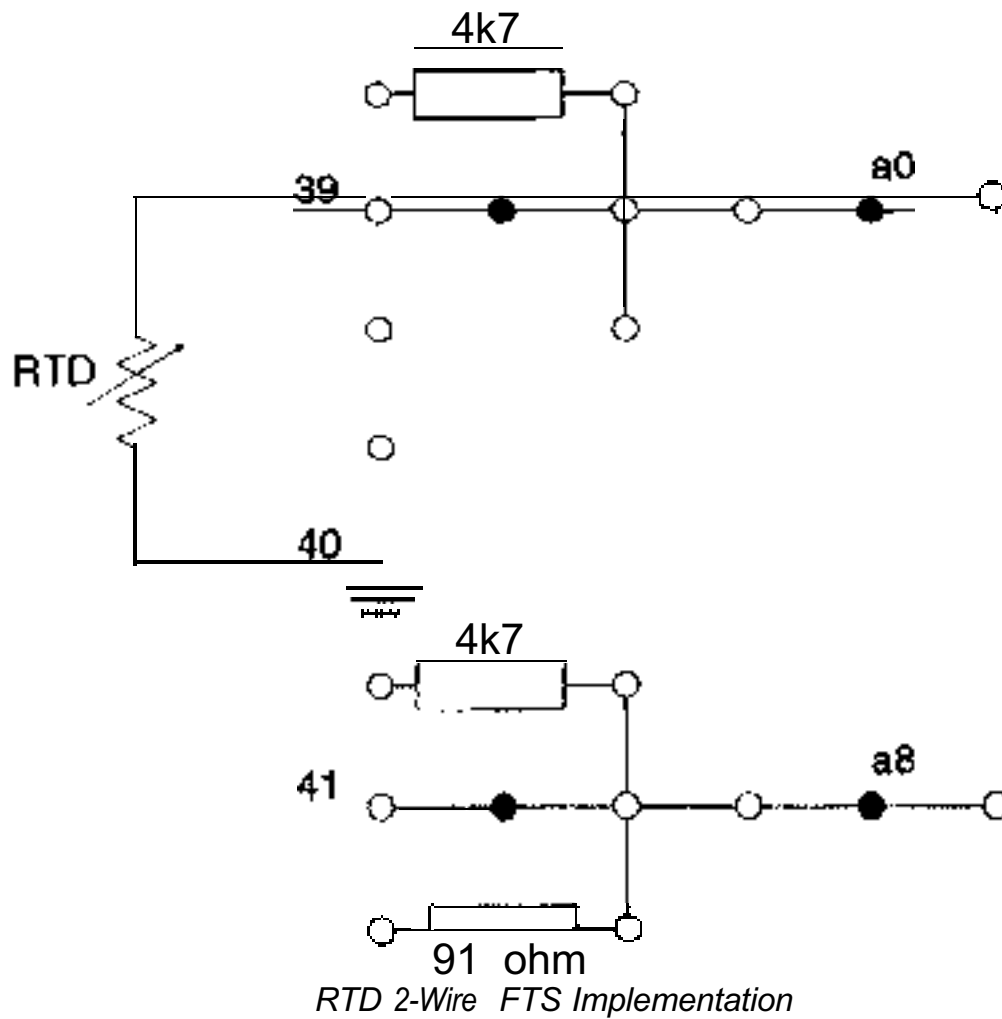
## 5.2.2 RTD Completion Circuits

There are three methods of connecting the PT100 to a Data Logger which differ in the number of wires connected to the PT100. To convert the resistance variation to a voltage variation a current is applied to the RTD producing a voltage across the RTD which can be measured. Errors are introduced by resistances in the wires between the voltage measurement device and the RTD. In all three circuits a bridge network is used to remove the constant offset voltage which otherwise would require a higher input range and would limit the resolution.

### 5.2.2.1 2-wire Completion Circuit

The 2-wire circuit is the simplest method of connecting the RTD but provides no compensation for lead resistance. A circuit is shown below. A diagram showing how this may be implemented on a Field Termination Strip appears on the next page.



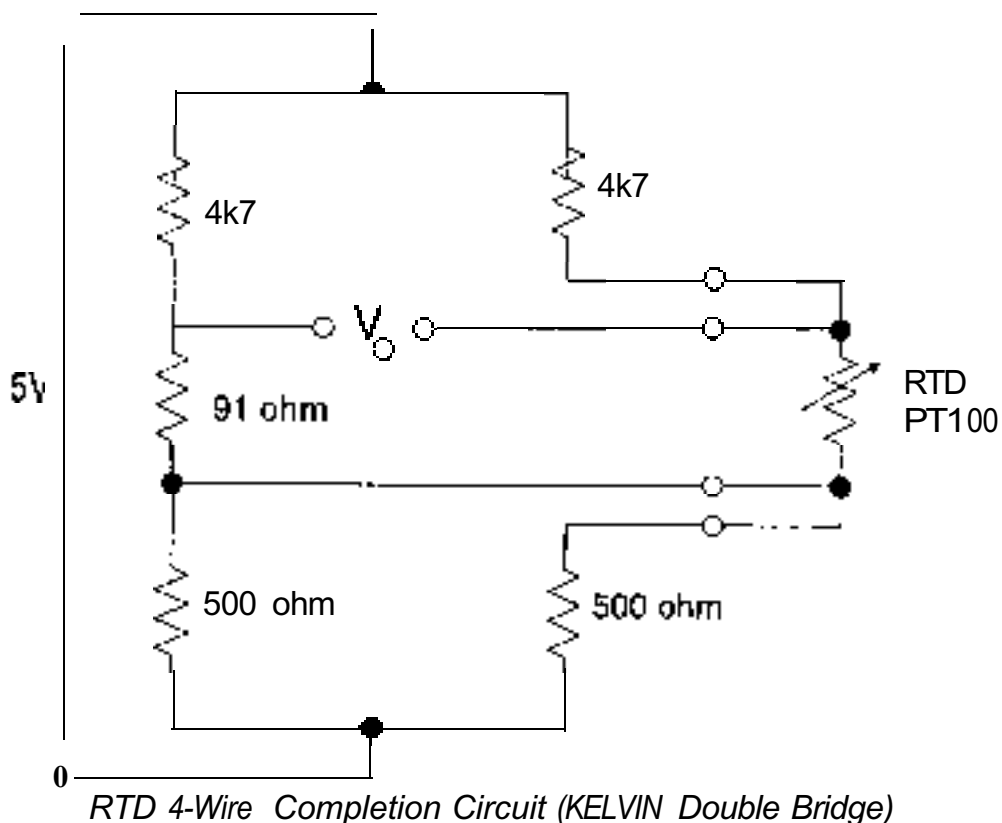


### 5.2.2.2 3-wire Completion Circuit

The 3-wire circuit partially compensates for the lead resistance by putting a lead resistance in each half of the bridge so balancing them out. This is not much harder to implement than the 2-wire circuit but provides greater accuracy. This circuit is recommended for most situations. A circuit is shown on page 14 along with a diagram showing how this may be implemented on a Field Termination Strip.

### 5.2.2.3 4-Wire Completion Circuit

The 4-wire circuit reduces the effect of lead resistance by applying the current to the device through different leads to the leads connected to the voltage measurement device. A circuit diagram for the 4-wire circuit is shown below but it is not suitable for direct implementation on the Field Termination Strip.



## 6. CALIBRATION

### 6.1 Thermocouple Calibration

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The Thermocouple is calibrated only by means of a software formula.

### 6.2 PT100 Calibration

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The Platinum resistance sensor is not strictly a linear device. For the range of -20 to 60°C chosen above, the device is reasonably linear with a maximum error of 0.13°C and therefore no correction formula has been employed. Other fixed errors may arise due to the values of the resistors in the bridge circuit not being exact. It is, therefore, recommended that the following procedure be carried out.

#### 6.2.1 Procedure

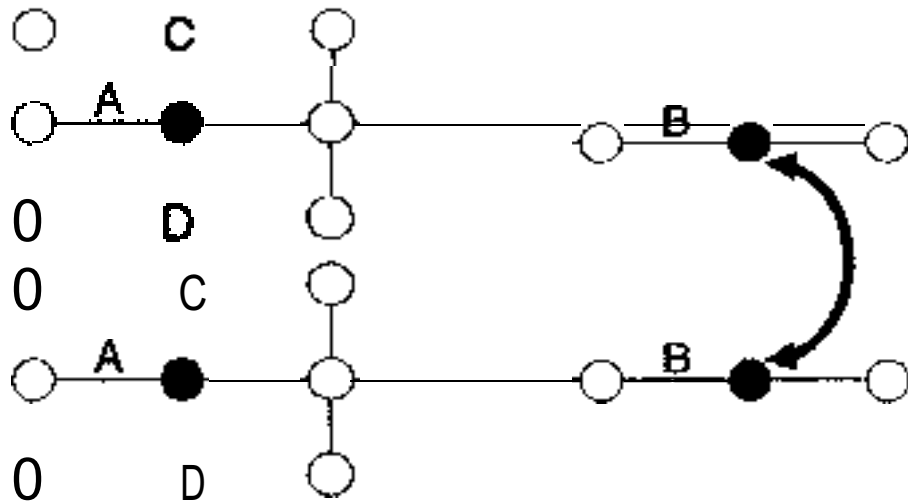
The equipment required to carry out the calibration is a decade resistance box, a digital multimeter, a computer and STARLOG software.

Complete the bridge on the MACRO Field Termination strip (section 3) and connect to the MACRO logger. Turn on the 5V voltage from the logger to power the bridge continuously by selecting the following commands:

1. **Test a Logger**
2. Space Bar
3. **MDL Diagnostics**
4. Alt-D

Wait for the screen to return an asterisk.

Replace the PT100 sensor with the resistance decade box and set the box to the lowest value of the range to be measured, using the tables in Appendix B, e.g. 92.16 for -20°C. Measure the voltage between the two solder links "B" on the Field Termination Strip. Change the resistance to the highest value of the range, e.g. 123.24 for 60°C and measure the voltage this produces.



*Measure the voltage between solder links "labelled B"*

5. Press K on the computer to return the logger to its default configuration.
6. Press Alt-X to exit MDL Diagnostics.

The voltages obtained should be entered as the "Transducer Range mV" when creating or editing the transducer to correspond to the "Transducer Scaling/Formula" for the chosen temperature range.

## 7. SPECIFICATIONS

### 7.1 Type K Welded Tip Thermocouple

Operating Temperature: -50°C to 480°C  
Positive arm: Nickel/Chromium brown/white  
Negative arm: Nickel/Aluminium blue/white  
Wire conductor: solid, 0.3 mm diameter each  
Cable: extension wire, Type K, 5 m supplied  
Colour coding: in accordance with BS 1843  
Size: 1.6 mm diameter

### 7.2 Thermocouple Mounting Tape

Temperature Range: -20°C to 310°C  
Material: polyimide  
Size: 12 mm W, 33 m roll

## **Appendix A**

### **The Formula for a K Type Thermocouple**

The formula in the file PDL0UT.FOR is shown below:

```
:Ktherm  
pushv  
0.01221  
mul  
24.18379686  
mul  
0  
rc1  
add
```

This formula assumes that the thermocouple is linear and multiplies by a fixed constant and adds the cold junction temperature.

## Appendix B

### Resistance/Temperature Relationship for K-Type Thermocouple

<b>(°C)</b>	<b>0,0</b>	<b>2,0</b>	<b>-4,0</b>	<b>-6,0</b>	<b>-8,0</b>
<b>-50,00</b>	80,31	83,48	82,69	81,89	81,10
<b>-40,00</b>	84,27	87,43	86,64	85,85	85,06
<b>-30,00</b>	88,22	91,37	90,59	89,80	89,01
<b>-20,00</b>	92,16	95,30	94,52	93,73	92,95
<b>-10,00</b>	96,09	99,22	99,22	97,65	96,87
<b>0,00</b>	100,00				
<b>(°C)</b>	<b>0,0</b>	<b>+2,0</b>	<b>+4,0</b>	<b>+6,0</b>	<b>+8,0</b>
<b>0,00</b>	100,00	100,78	101,56	102,34	103,12
<b>10,00</b>	103,90	104,68	105,46	106,24	107,02
<b>20,00</b>	107,79	108,57	109,35	110,12	110,90
<b>30,00</b>	111,67	112,45	113,22	113,99	114,77
<b>40,00</b>	115,54	116,31	117,08	117,85	118,62
<b>50,00</b>	119,39	120,16	120,93	121,70	122,47
<b>60,00</b>	123,24	124,01	124,77	125,54	126,31
<b>70,00</b>	127,07	127,84	128,60	129,37	130,13
<b>80,00</b>	130,89	131,66	132,42	133,18	133,94
<b>90,00</b>	134,70	135,46	136,22	136,98	137,74
<b>100,00</b>	138,50	139,26	140,02	140,77	141,53
<b>110,00</b>	142,29	143,04	143,80	144,55	145,31
<b>120,00</b>	146,06	146,81	147,57	148,32	149,07
<b>130,00</b>	149,82	150,57	151,33	152,08	152,83
<b>140,00</b>	153,57	154,32	155,07	155,82	156,57
<b>150,00</b>	157,31	158,06	158,81	159,55	160,30
<b>160,00</b>	161,04	161,79	162,53	163,27	164,02
<b>170,00</b>	164,76	165,50	166,24	166,98	167,72
<b>180,00</b>	168,46	169,20	169,20	170,68	171,42
<b>190,00</b>	172,16	172,89	172,89	174,37	175,10
<b>Table continued on the next page...</b>					

(°C)	0,0	+2,0	+4,0	+6,0	+8,0
200,00	175,84	176,57	177,31	178,04	178,78
210,00	179,51	180,24	180,97	181,71	182,44
220,00	183,17	183,90	184,63	185,36	186,09
230,00	186,81	187,54	188,27	189,00	189,72
240,00	190,45	191,18	191,90	192,63	193,35
250,00	194,07	194,80	195,52	196,24	196,96
260,00	197,69	198,41	199,13	199,85	200,57
270,00	210,29	202,01	202,72	203,44	204,16
280,00	204,88	205,59	206,31	207,02	207,74
290,00	208,45	209,17	209,88	210,59	211,31
300,00	212,02	212,73	213,44	214,15	214,86
310,00	215,57	216,28	216,99	217,70	218,41
320,00	219,11	219,82	220,53	221,23	221,94
330,00	222,65	223,35	224,05	224,76	225,46
340,00	226,17	226,87	227,57	228,27	228,97
350,00	229,67	230,37	231,07	231,77	232,47
360,00	233,17	233,87	234,56	235,26	235,96
370,00	236,65	237,35	238,04	238,74	239,43
380,00	240,13	240,82	241,51	242,20	242,20
390,00	243,59	244,28	244,97	245,66	246,35
400,00	247,04	247,73	248,41	249,10	249,79
410,00	250,48	251,16	251,16	252,10	253,22
420,00	253,90	254,59	254,59	255,95	256,63
430,00	257,32	258,00	258,68	259,36	260,04
440,00	260,72	261,40	262,08	262,76	263,43
450,00	264,11	264,79	265,46	266,14	266,82
460,00	267,49	268,17	268,84	269,51	270,19
470,00	270,86	271,53	272,20	272,88	273,55
480,00	274,22	274,89	275,56	276,23	276,89
490,00	277,56	278,23	278,90	279,56	280,23
500,00	280,90				